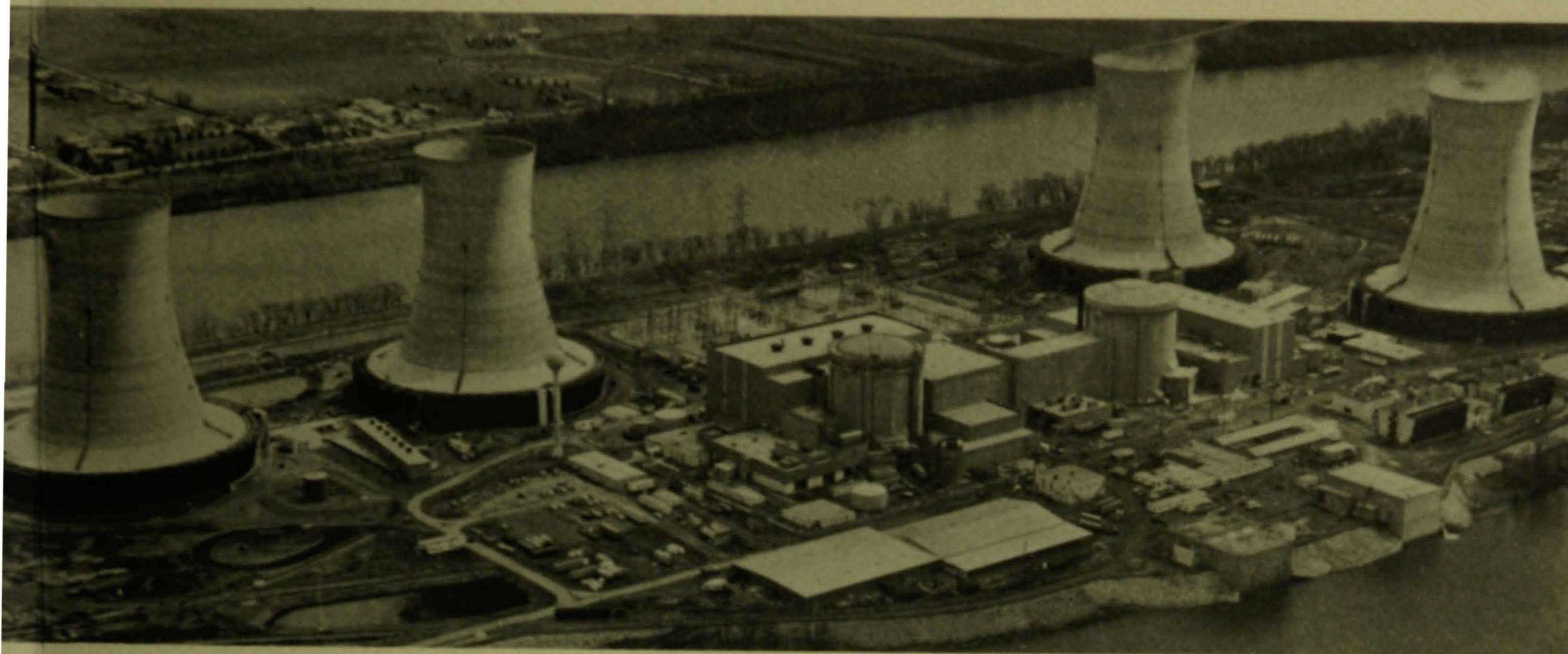
GEND-INF- 018
December 1984



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GEND

General Public Utilities • Electric Power Research Institute • U.S. Nuclear Regulatory Commission • U.S. Department of Energy

EXAMINATION OF SOLENOID VALVES AH-EP-5037 AND AH-EP-5039 AND LIMIT SWITCHES AH-KS-5037 AND AH-KS-5039

Florante T. Soberano

Prepared for the
U.S. Department of Energy
Three Mile Island Operations Office
Under DOE Contract No. DE-AC07-76ID01570

DISCLAIMER

GEND-INF-018

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ABSTRACT

Two ASCO solenoid valves and their associated NAMCO limit switches, all classified as Class 1E items, were removed from the TMI-2 Reactor Building for detailed testing and hands-on examination to determine and evaluate their degree of degradation resulting from their exposure to the accident environment. This report discusses the methods and types of tests performed on the components, the analysis and evaluation of the test results, and the recommendations for system improvement.

ACKNOWLEDGMENTS

The examinations were performed at Auxiliary Reactor Area III at the Idaho National Engineering Laboratory. The author expresses appreciation to the following EG&G Idaho personnel for their assistance: Rolf C. Strahm, project coordinator; Robert L. Rowe, supervisor; Ronald E. Thurman, examiner; and Jack N. Earley, technical editor.

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APPENDICES

INTRODUCTION

NRC I&E Bulletin No. 79-01A (Appendix A) cited pilot solenoid valves AH-EP-5037 and AH-EP-5039 as unqualified for a Class 1E function inside a primary containment. The deficiency of these valves concerns the use of parts made of acetal plastic and elastomers. These materials are known to have a low damage threshold to radiation and temperature. Exposure of these materials to the environmental extremes of an accident such as that at Three Mile Island Unit Two (TMI-2) in March 1979 may render the valves inoperative.

Valves AH-EP-5039 and AH-EP-5037 are the pilot solenoid valves of containment purge system inboard containment isolation supply valves AH-V2A and AH-V2B, respectively; AH-KS-5039 and AH-KS-5037 are the corresponding limit switches. Both valve systems are Class 1E; they operated during containment isolation following the hydrogen burn and were operated regularly during the long term recovery operation.

AH-V2A and AH-V2B, as well as AH-V3A (purge return isolation), were tested during the in situ testing program. AH-V2A and AH-V2B tested satisfactorily. AH-V3A operated during the two instances that it was tested; however, intermittently, the indicating light that signifies the valve is fully open failed to light, indicating that the valve is either not making its full stroke or the OPEN limit switch is improperly set or defective. Incomplete stroke is usually caused by leakage in the air system, i.e., excessive leakage prevents the development of full operating pressure in the actuator cylinder.

The anomaly exhibited by AH-V3A in conjunction with the deficiencies cited in Bulletin 79-01A prompted examination of the pilot solenoid valves and the associated limit switches. Originally, the plan was to examine AH-EP-5040 and AH-KS-5040, the pilot solenoid valve and limit switches of AH-V3A. However, because of the degree of difficulty involved in removing the selected components, the units corresponding to AH-V2A and AH-V2B were examined instead. Accessibility problems also precluded removing the pilot solenoid valve of AH-V2B; only the solenoid coil and limit switches were removed. Solenoid valve AH-EP-5039 and limit switch AH-KS-5039 were removed in their entirety.

DESCRIPTION

The purge valves are 30 in. butterfly valves operated by a pneumatic actuator. The air to operate the valves is furnished by the respective pilot solenoid valve. Each purge valve is also provided with two limit switches, i.e., one to actuate when the valve is fully closed and the other to actuate when the valve is fully open.

The pilot solenoid valves are normally-closed three-way 1-1/4 in. pilot controlled piston operated ASCO model HT8331A45 (Figure 1). Each unit has a 120 V ac solenoid coil, with class HT insulation, housed in a NEMA 4 enclosure. The valve, shown in an exploded view in Figure 2, contains parts that are made of low radiation-tolerant materials. The bottom plug and disk holder of the pilot valves are made of acetal plastic. The gaskets, O-rings, and main valve disks are made of Buna-N elastomers, reported to have a damage threshold of 7×10^6 rads. A typical valve is shown in its installed position in Figure 3.

The limit switches are NAMCO model EA740-20000 with snap-action switching. This model is loss-of-coolant accident (LOCA)-qualified; however, the TMI-2 units are not since they were manufactured before the qualification standard was put into effect. The vintage units and current models are identical in design; however, the vintage units contain parts made of materials that are not radiation tolerant. The switches are mounted on their respective valve and are actuated by a cam that is attached to the purge valve position indicator plate as shown in Figure 4.

AH-V2A and AH-V2B have the same control scheme, as shown in Figure 5, and share the same cabling, as shown in Figure 6.

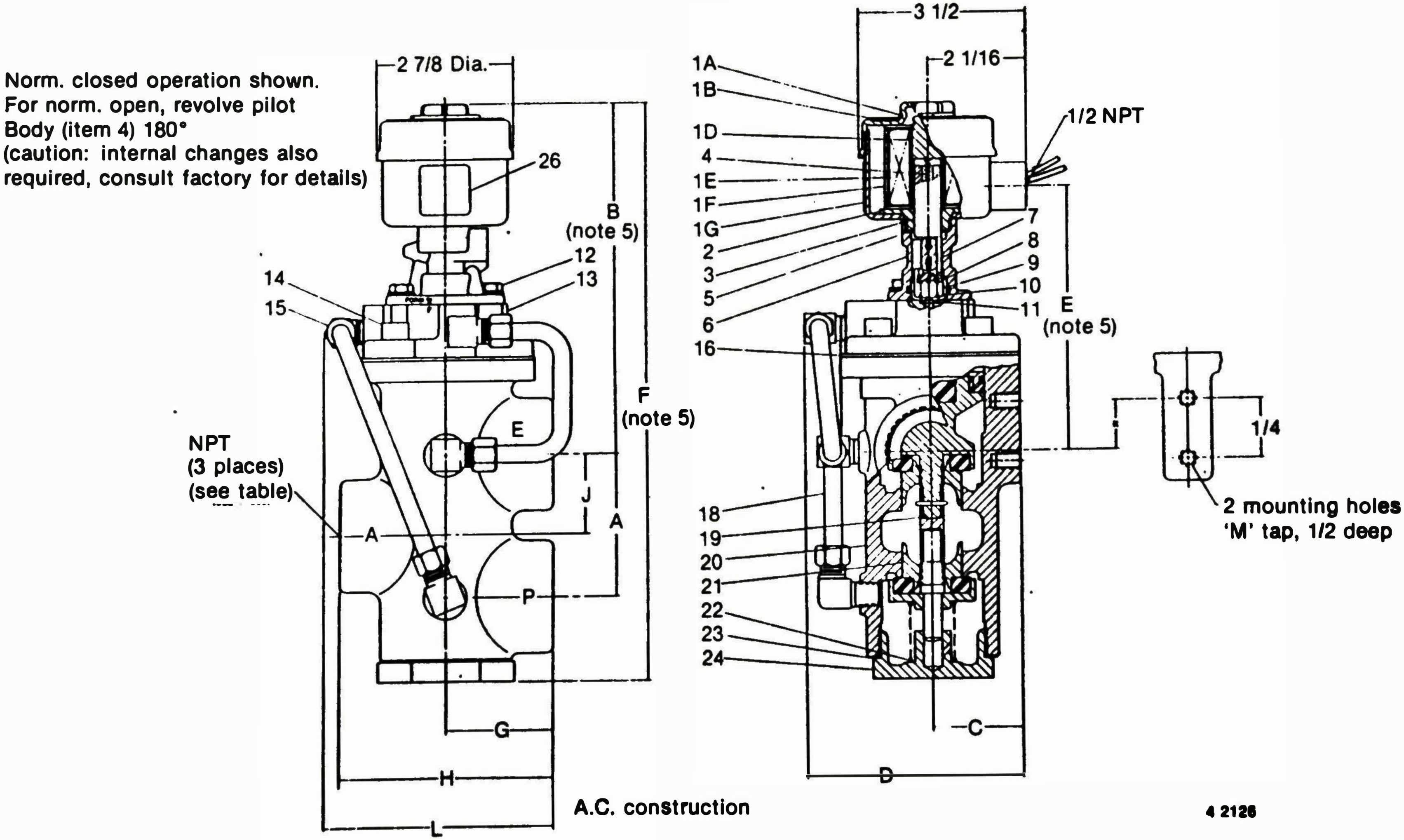

Figure 1. Detail of ASCO solenoid valve model HT8331A45.

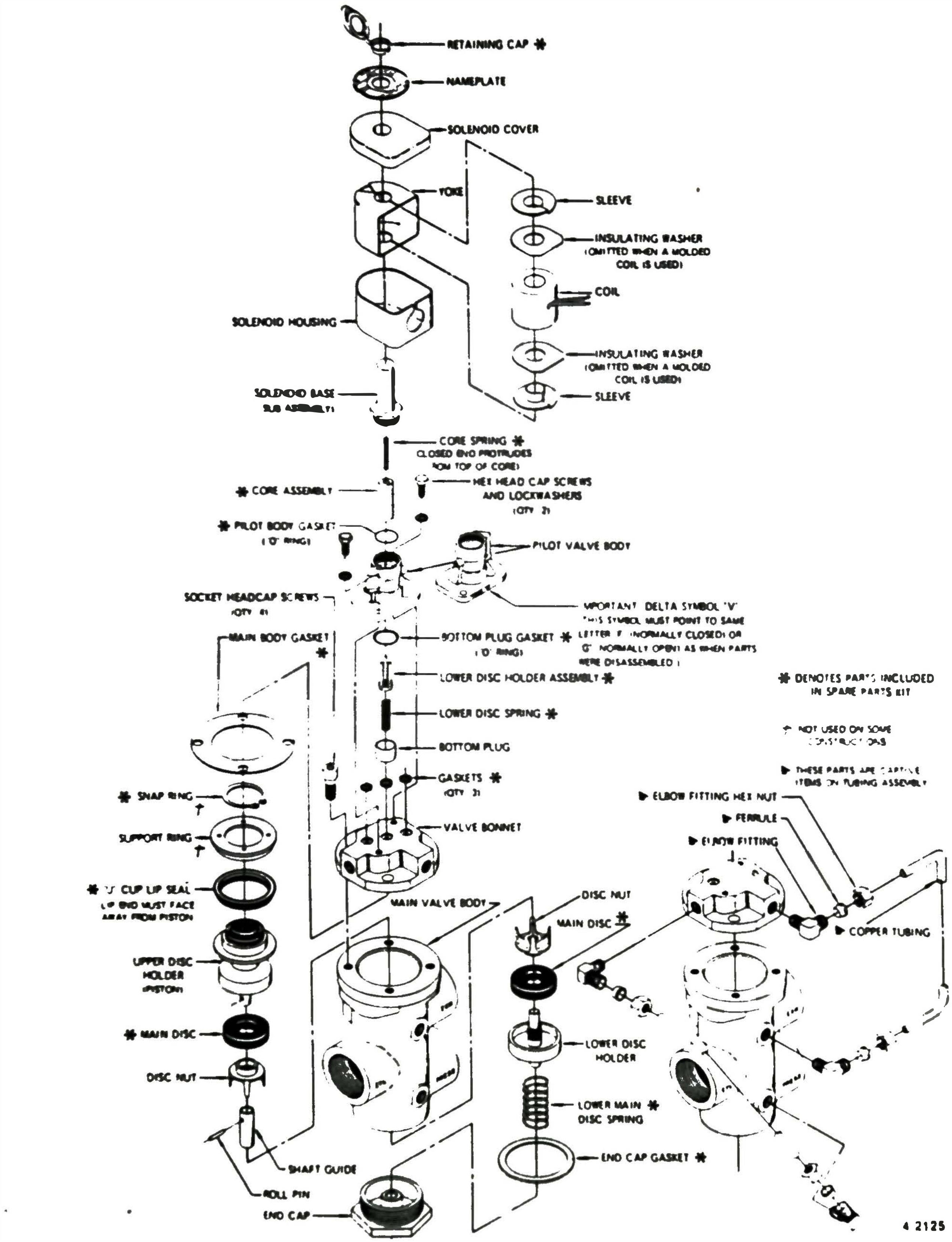

Figure 2. Exploded view of ASCO solenoid valve model HT8331A45.

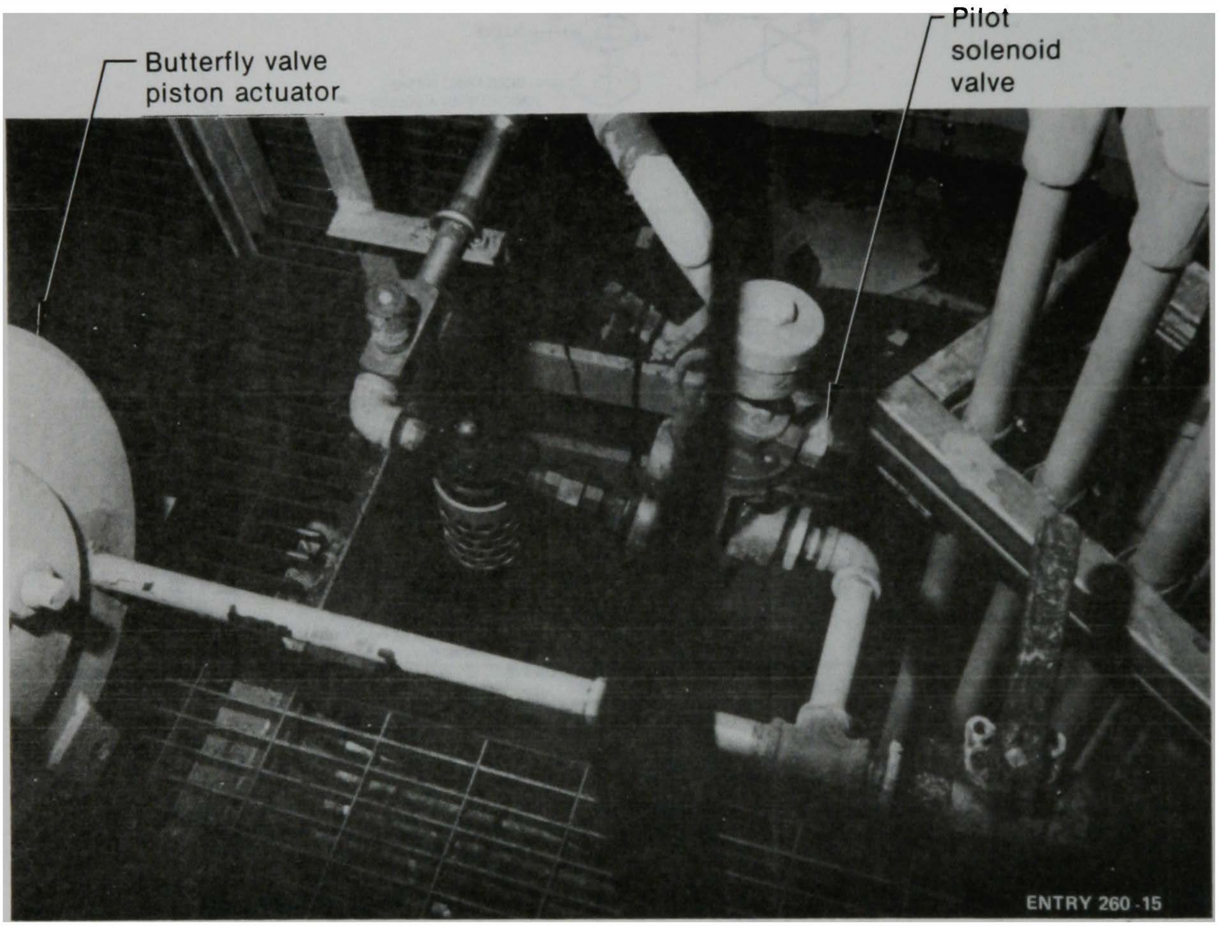

Figure 3. Installed location of a typical solenoid valve.

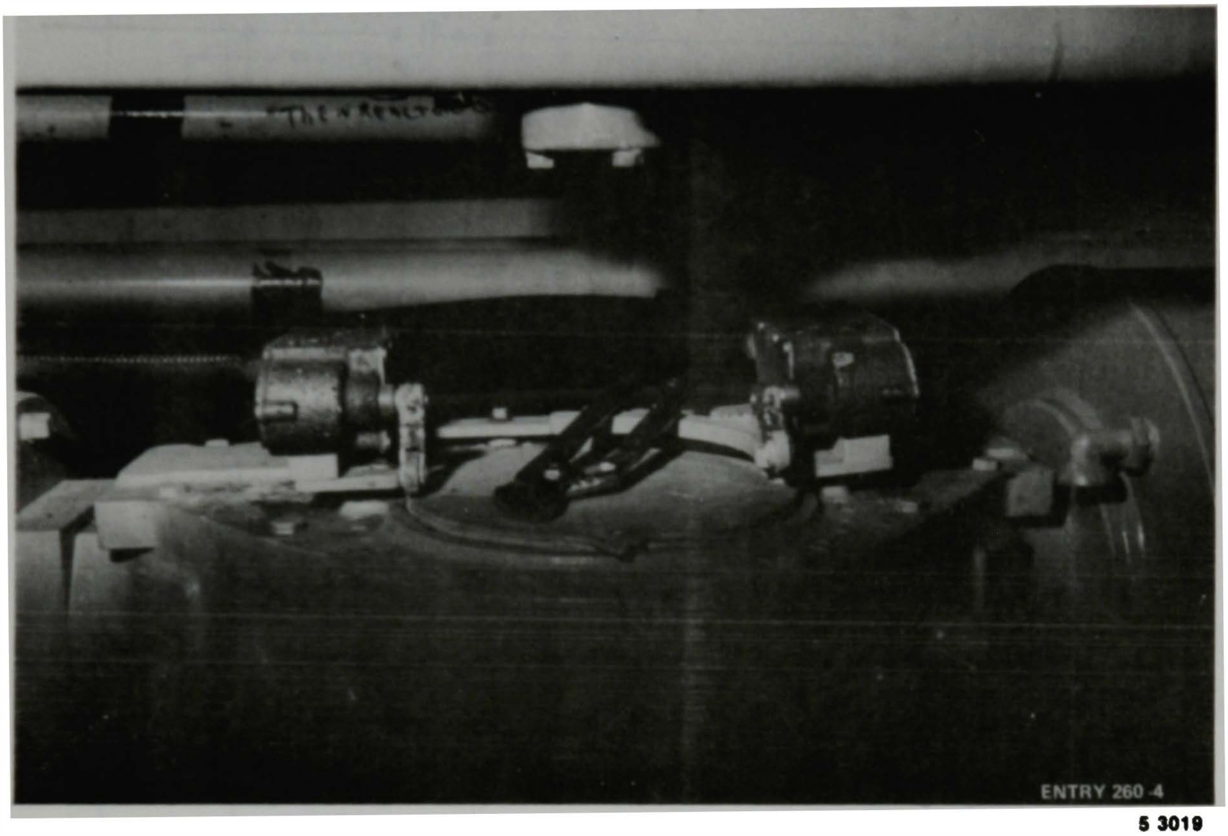

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Figure 4. Typical mounting detail of limit switches.

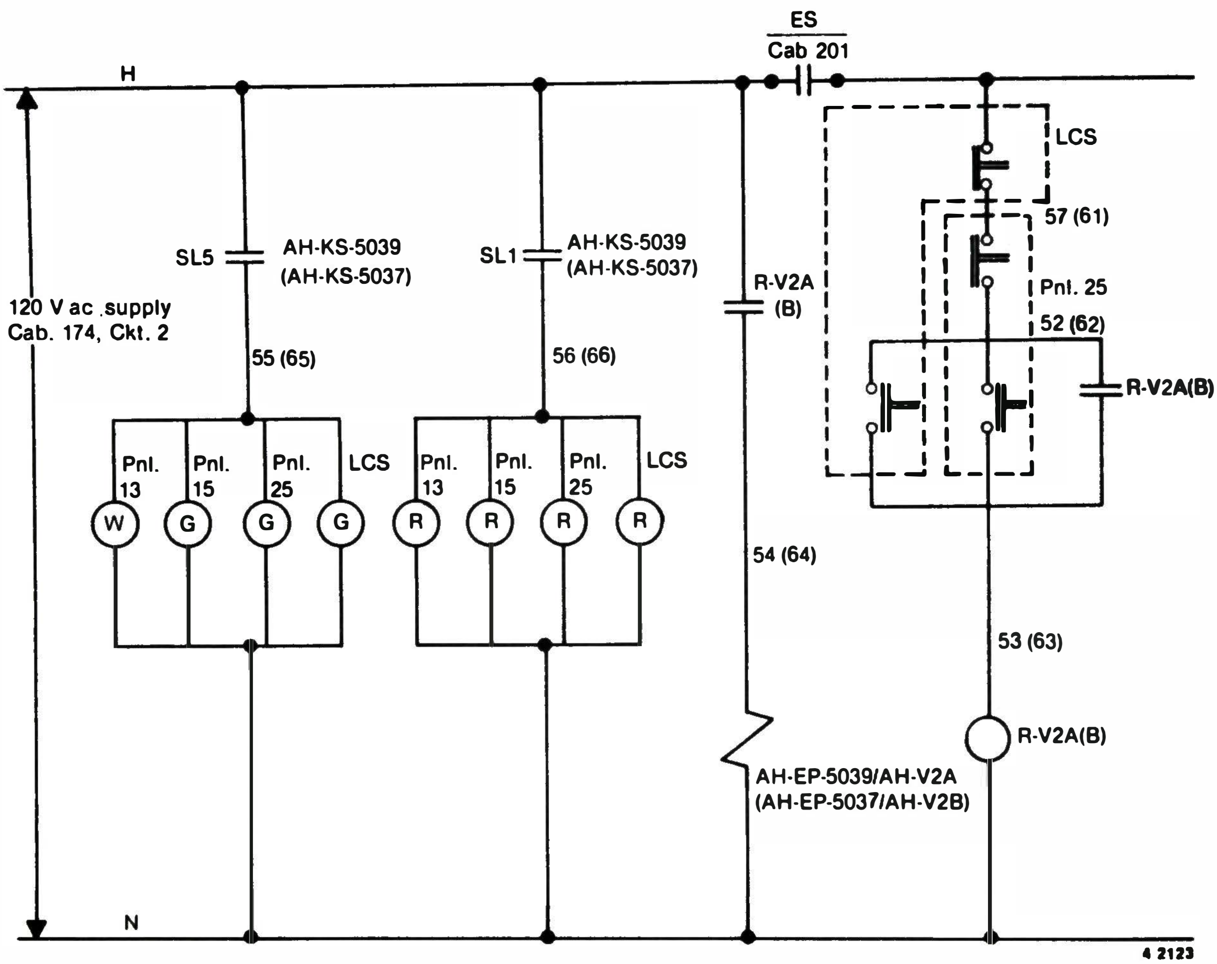

Figure 5. AH-V2A/AH-V2B control schematic.

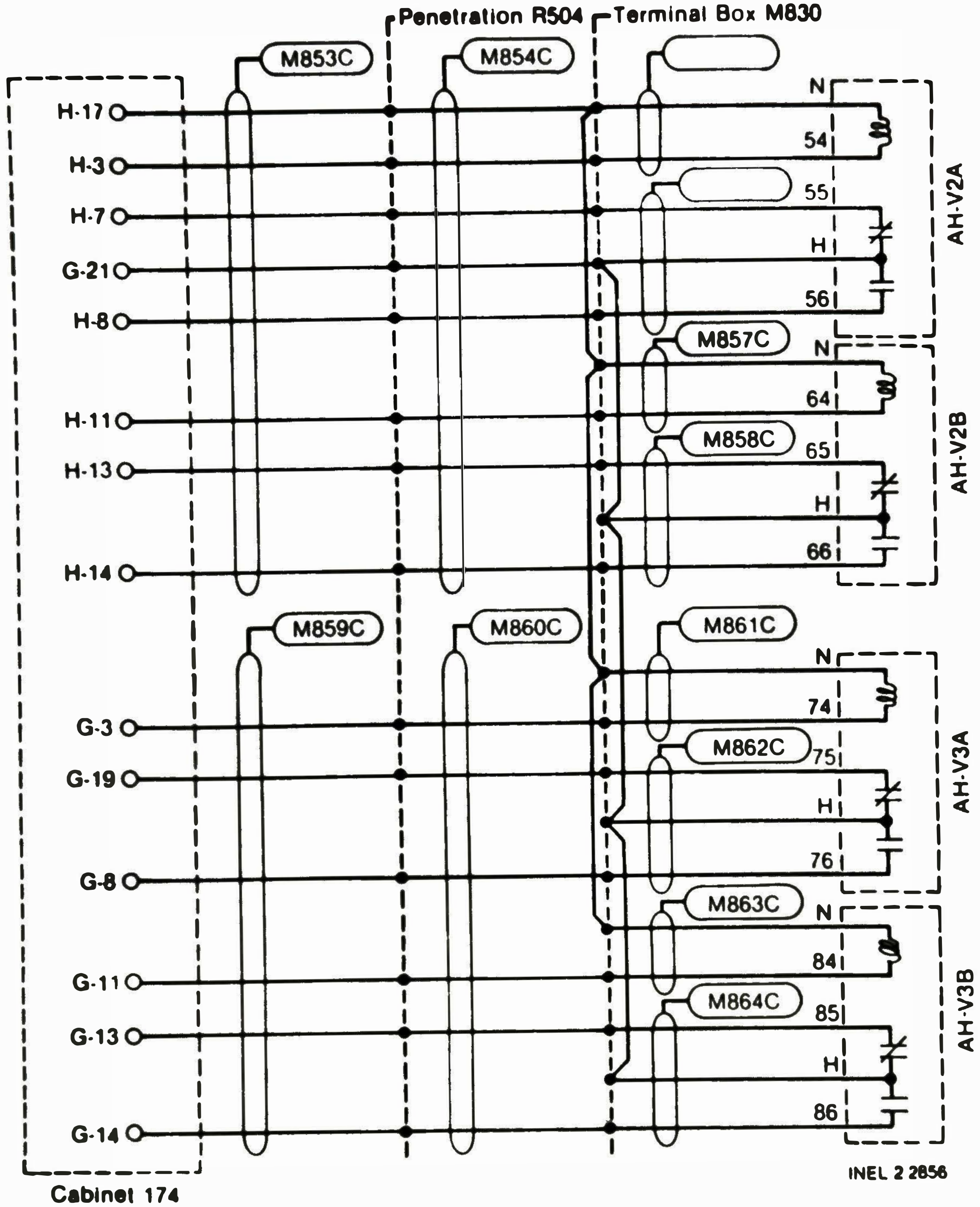

Figure 6. Interconnection wiring diagram of AH-V2A, -V2B, -V3A, and -V3B.

EXAMINATION

Examination of the solenoid valves and limit switches was performed at Idaho National Engineering Laboratory (INEL) Auxiliary Reactor Area III (ARA-3). Examination of the devices consisted of measurement of the electrical characteristics of each component, functional testing, disassembly, and visual examination of the parts. To establish a data base, a new and identical solenoid valve was tested in the same manner and with a setup identical to the TMI-2 components.

Electrical Characteristics Measurements

Measurement of the electrical characteristics of the solenoid coils was performed with the component in the valve assembly. The coil of AH-EP-5037 was tested with the valve body of AH-EP-5039. The test comprised measurement of the loop resistance, loop inductance, insulation resistance, and dielectric strength. In the dielectric strength measurement, a dielectric voltage withstand test was performed in lieu of dielectric breakdown test. The test voltages were 1240 V ac and 2200 V ac for the solenoid valves and limit switches, respectively.

Functional Tests

Functional tests involved operating the devices and measuring or observing the responses.

Limit Switches

The limit switch tests involved measurement of the operating torque, trip travel, and reset angles.

Solenoid Valves

The solenoid valve tests involved measurement of the in-rush and holding currents, response times, internal leakage, and pull-in and dropout voltages.

In-rush and holding currents were measured with full rated voltage of 120 V applied on the coil. A holding current measurement was also made with the test voltage of 102 V.

The opening response time of the solenoid valves was the time it took for the cylinder pressure to reach 90% of the inlet pressure following its energization. The closing response time was the time it took for the cylinder pressure to drop to 10% of its original pressure following solenoid valve deenergization. In the response time tests, the solenoid valve was piped such that the cylinder port was connected to a short piece of capped 1-1/2 in. pipe, the pressure port was connected to a steady supply of 100 psig nitrogen, and the exhaust port was left open to atmosphere. A fast response pressure transducer measured the cylinder pressure.

The internal leakage test was made at 12.5 psig and 250 psig with the solenoid valve both energized and deenergized.

The results of the solenoid valve electrical and operational characterization tests are summarized in Appendix B.

Following the testing, solenoid valve AH-EP-5039 and limit switches AH-KS-5037 and AH-KS-5039 were disassembled and their nonmetallic parts were examined in detail for deterioration.

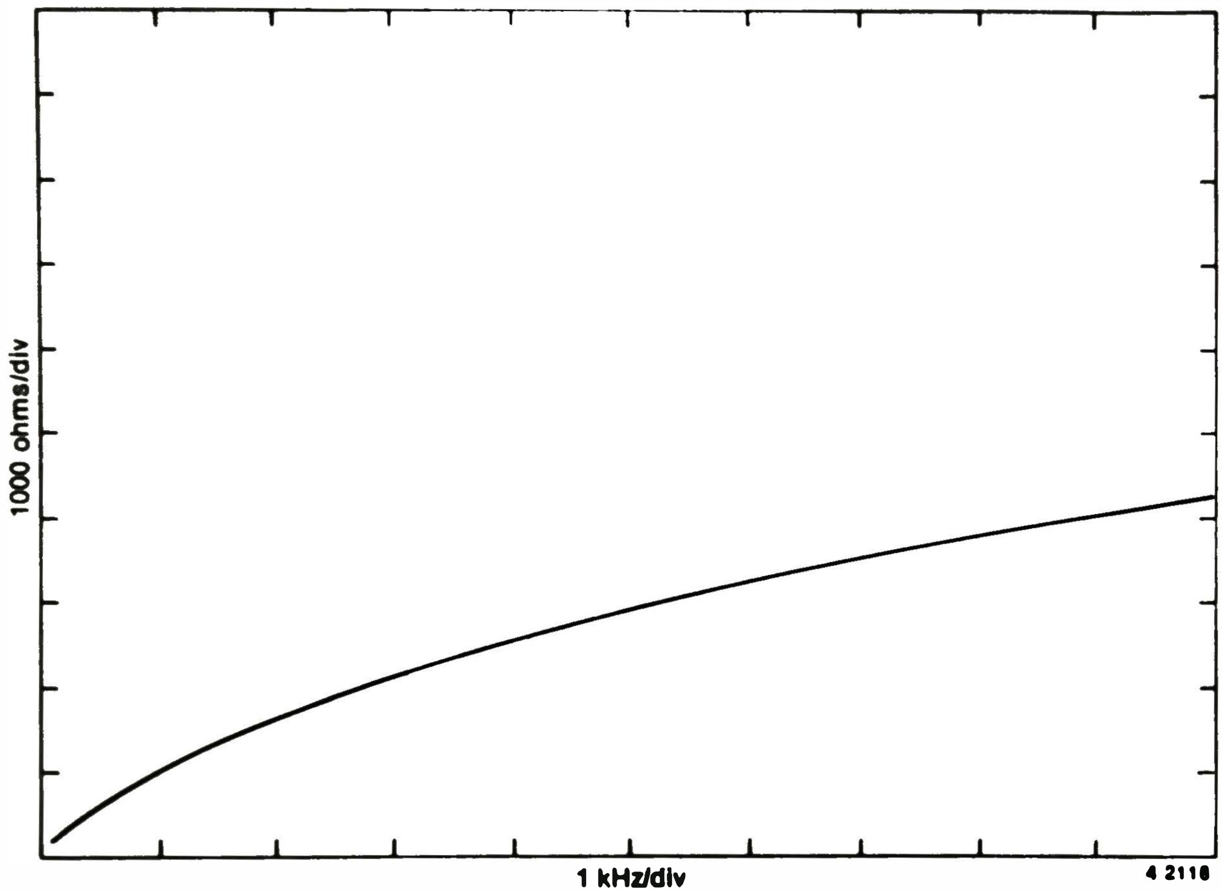

Figure 7. Equivalent series resistance pattern of test solenoid valve.

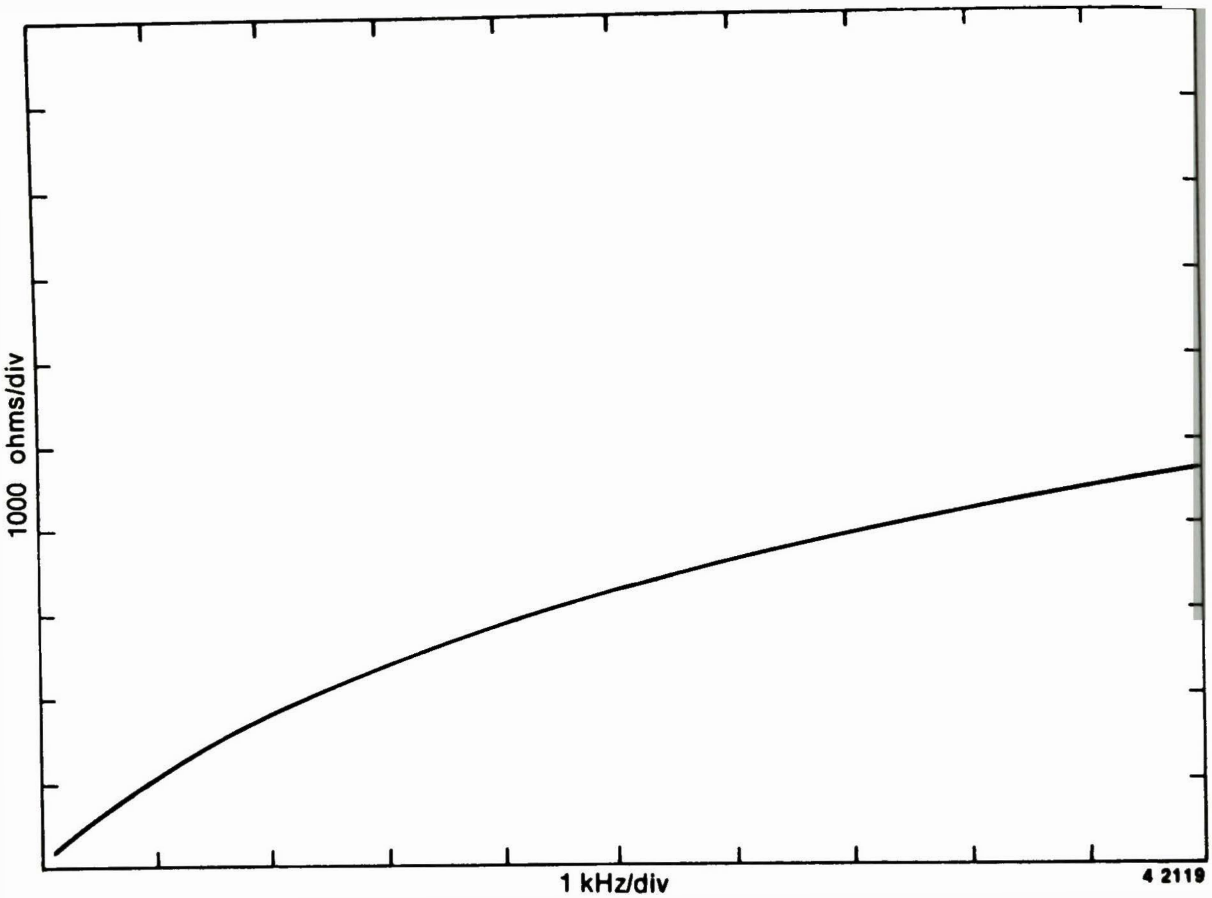

Figure 8. Equivalent series resistance pattern of solenoid valve AH-EP-5039.

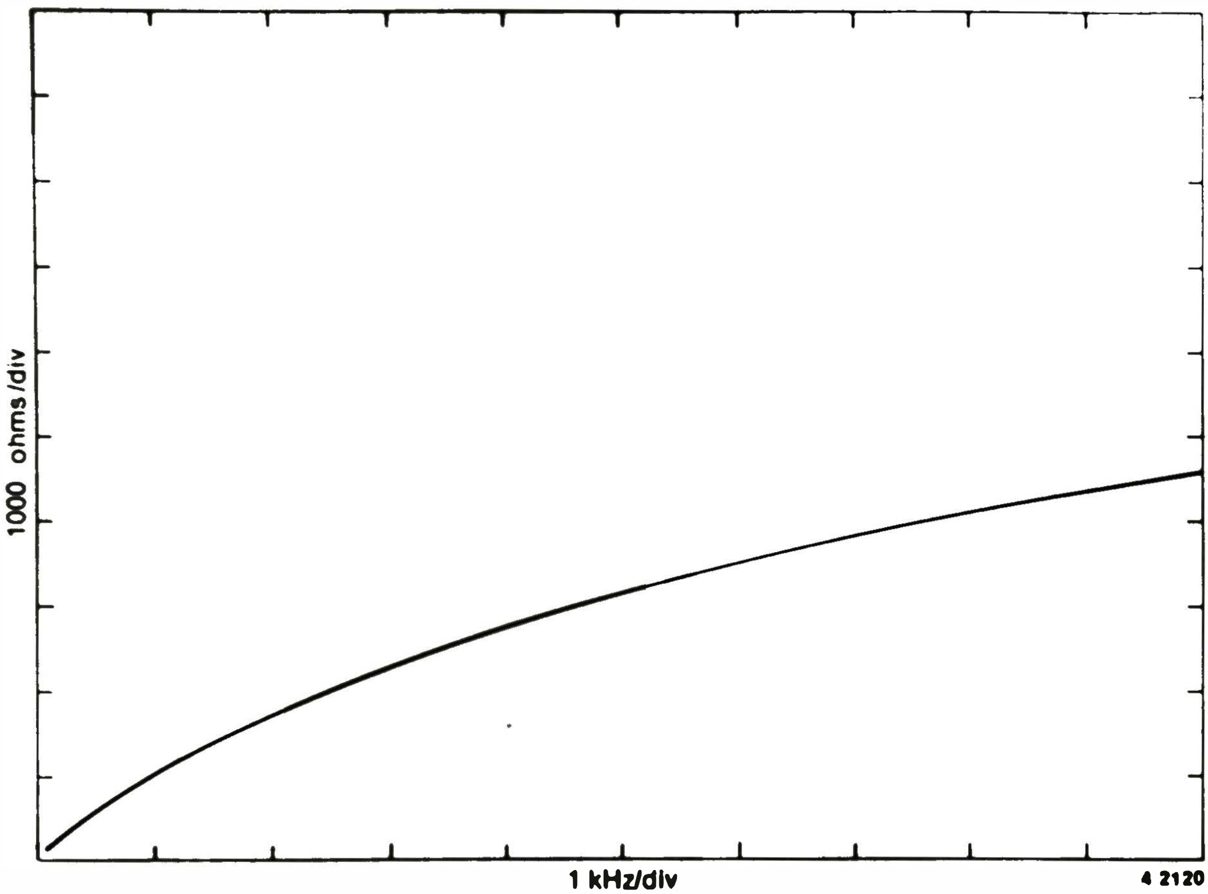

Figure 9. Equivalent series resistance pattern of solenoid valve AH-EP-5037.

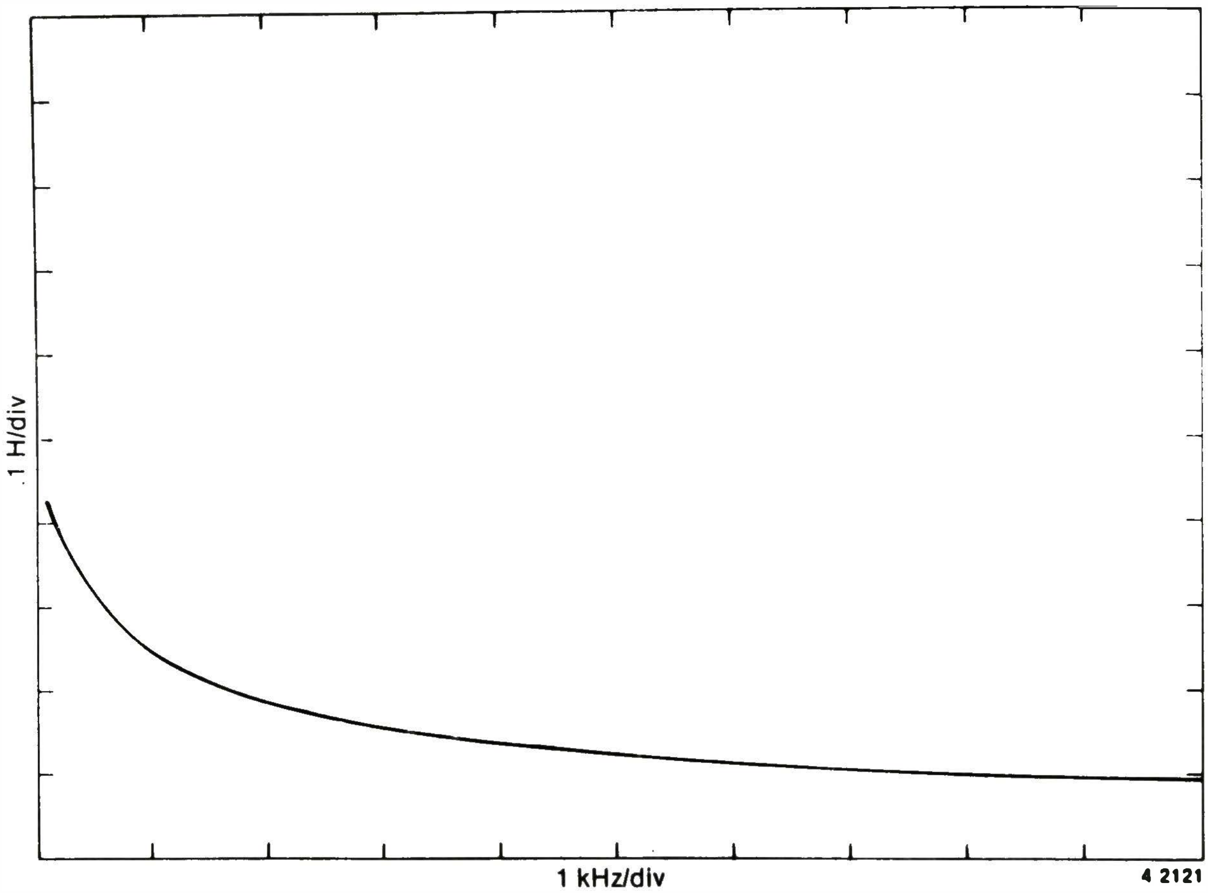

Figure 10. Effective inductance pattern of test solenoid valve.

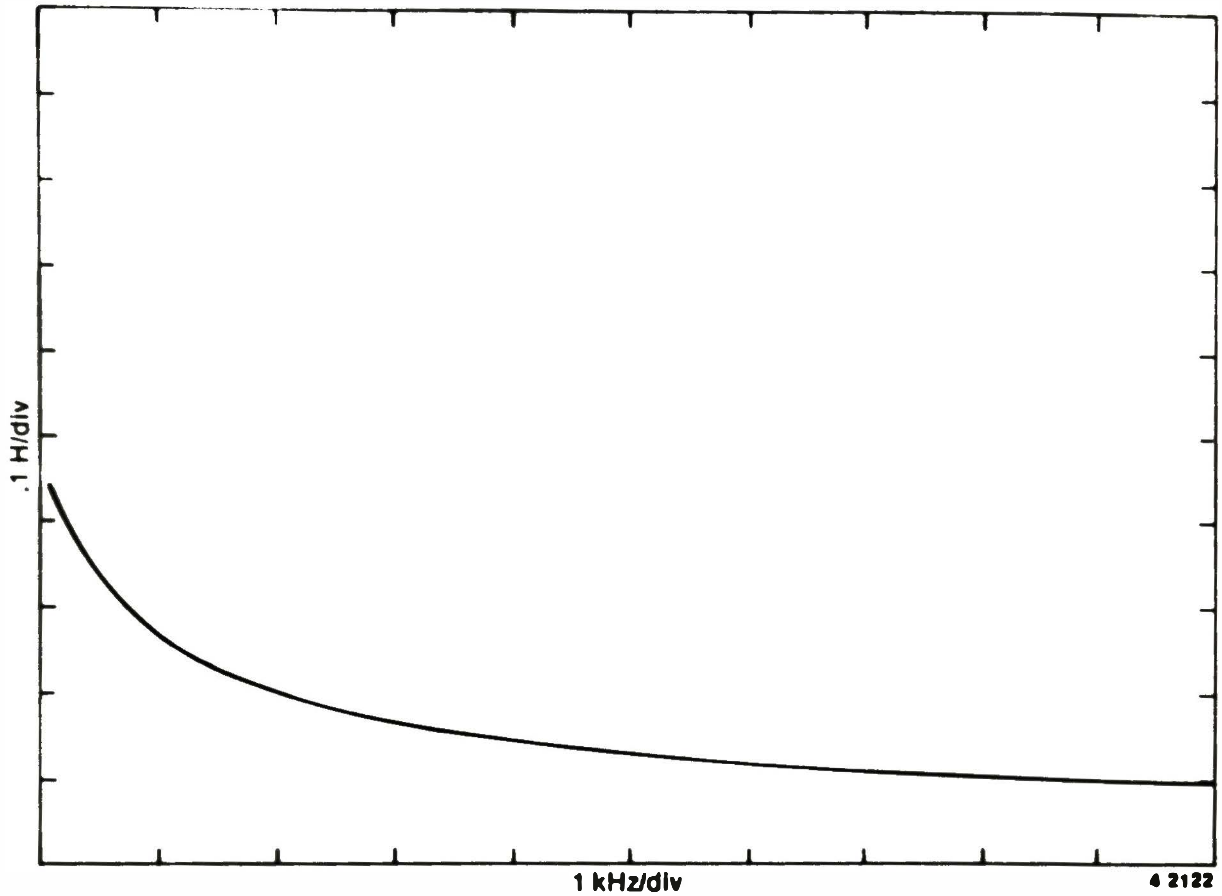

Figure 11. Effective inductance pattern of solenoid valve AH-EP-5039.

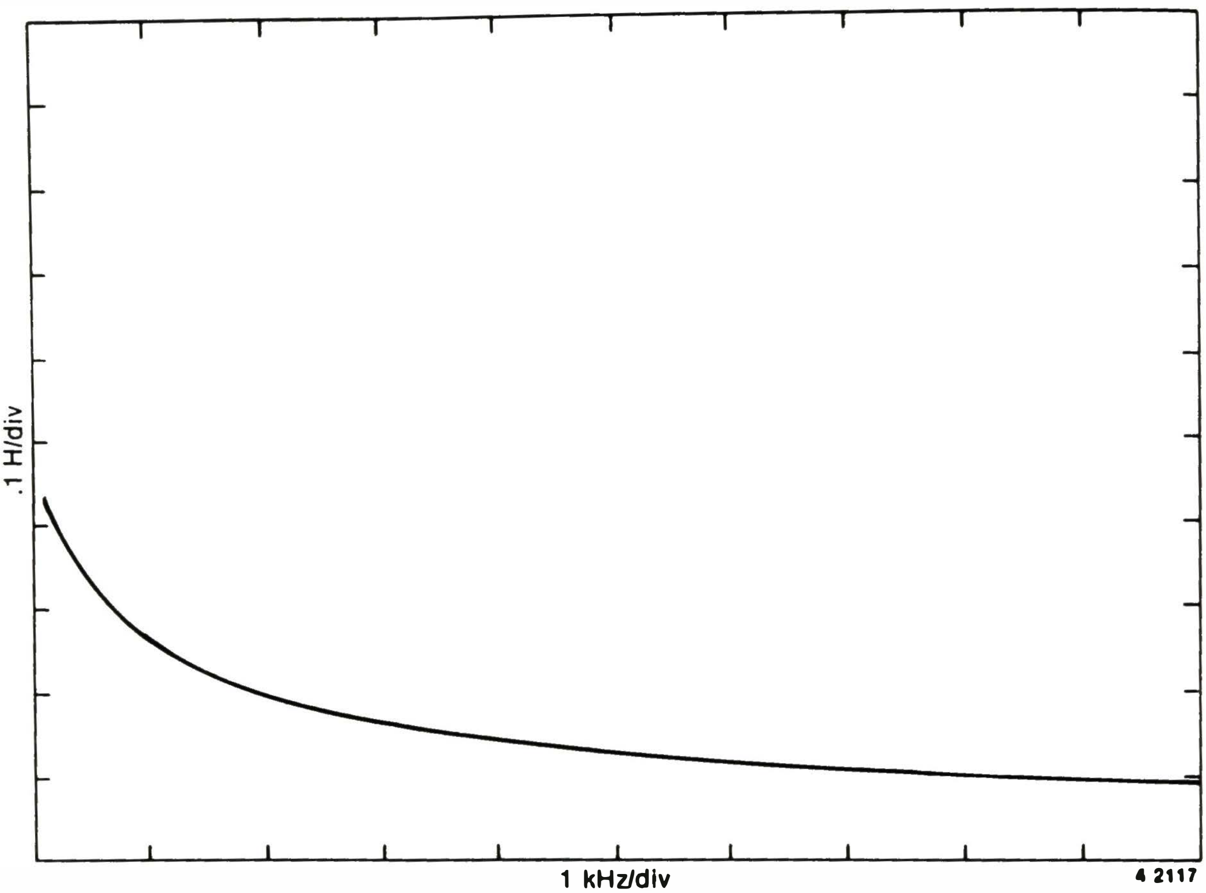

Figure 12. Effective inductance pattern of solenoid valve AH-EP-5037.

attributed either to radiation dose or aging. Nevertheless, the parts incurred no obvious mechanical property deterioration that affected the device operation or function. Likewise, the Buna-N materials used on the main valve disks, gaskets, and O-rings suffered no or inconsequential damage from the accident. The Buna-N, which has a relatively high resistance to radiation (approximately 7×10^6 rads) remained soft and pliable, with no evidence of hardening.

The limit switches likewise exhibited inconsequential damage from the accident. Rusting on the housing surface and embrittlement of the actuator shaft bushing are indications that the devices were exposed to the accident. Otherwise, all internal parts are shiny and clean and look new, as shown in Figure 13. The insides of all four limit switches were free of dirt and corrosion, and indicated no fluid damage, warping, or other damage to the switching mechanism parts. All the gaskets were in good condition except for a split on the switching mechanism cover gasket of AH-KS-5039. The gasket split was not caused by the accident--the gasket exhibited no loss of pliability.

The limit switches' mechanical and electrical properties also remained unaffected by the accident. Their respective insulation resistances, measured at 500 V dc, were greater than 10^9 ohms, a value indicative of insulation soundness. Likewise, the dielectric voltage withstand test of 2200 V ac caused no insulation breakdown on any of the switches. This result implies that the switches' stationary contact blocks and the movable contact carriers incurred minimal or no dielectric deterioration and incurred no contamination tracking. Mechanically, the snap-action operation of the switching mechanisms was normal. Each unit had consistent trip and reset angles, in close agreement with the design values of 18 and 14 degrees, respectively. Although the trip and reset angles differ slightly unit to unit, the variance was inconsequential and was not attributable to the accident. As seen in Figure 14, the trip and reset angles are primarily dependent on the profile of the cam and the cam follower.

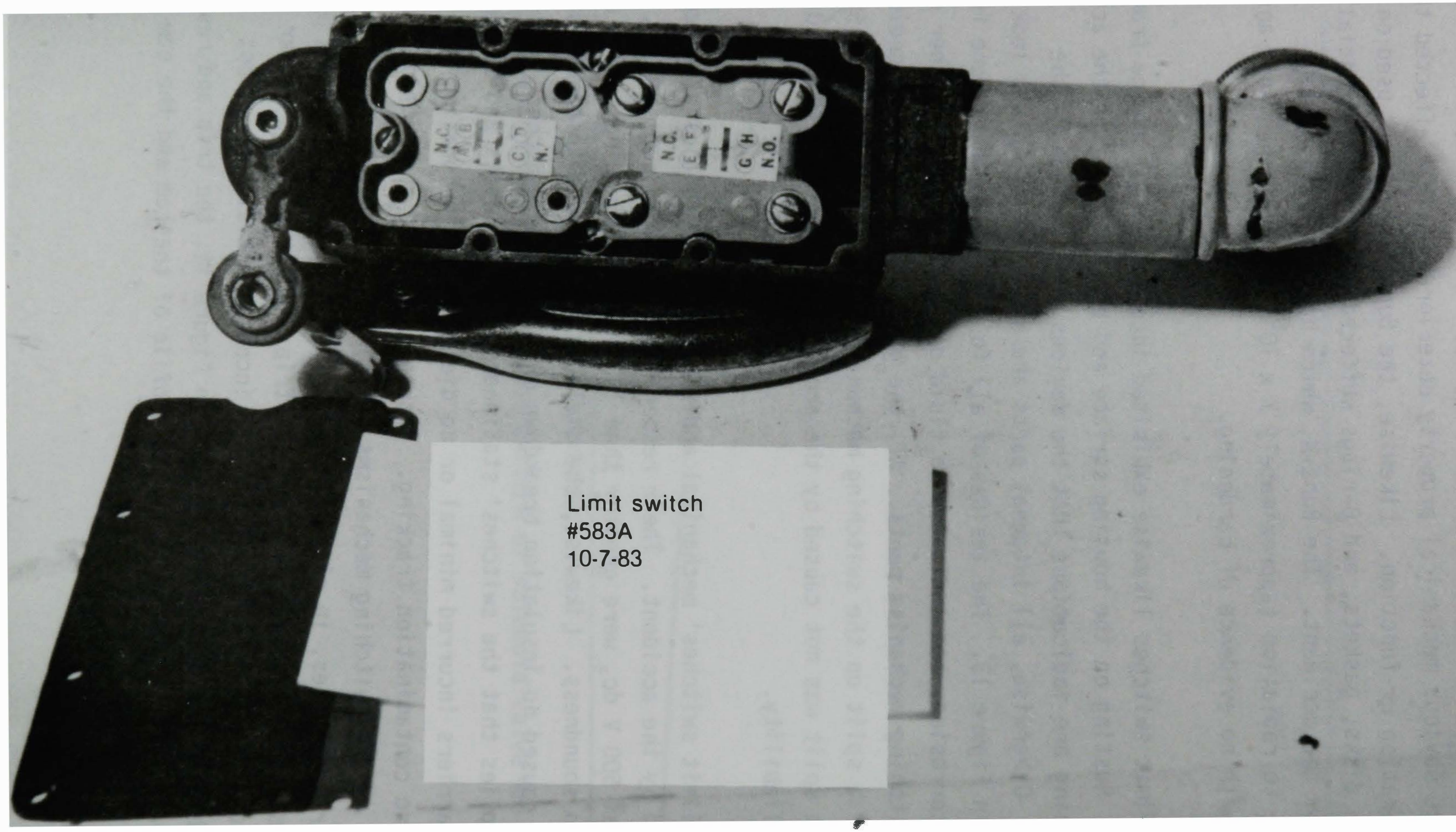

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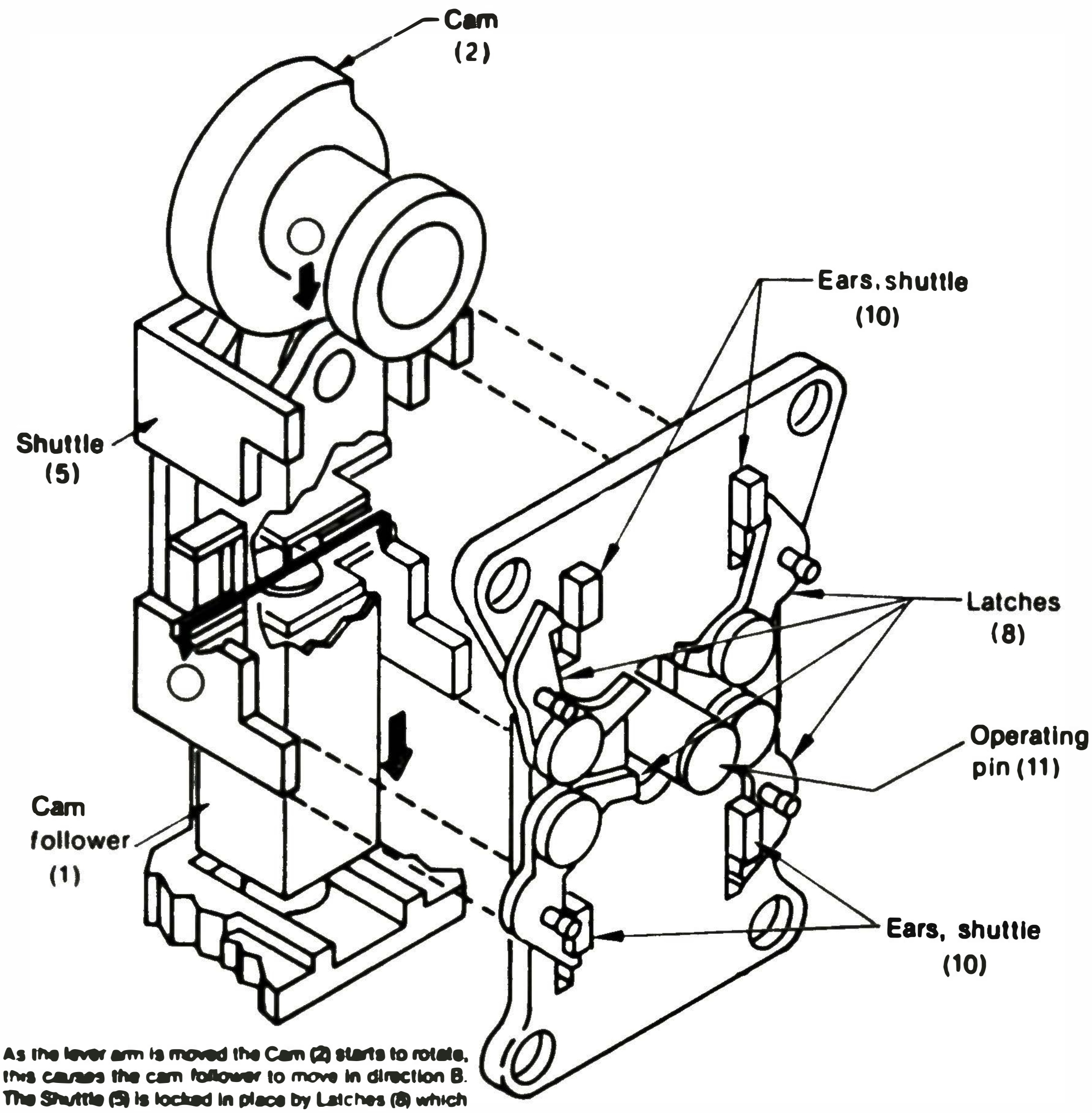
Figure 13. Exposed terminal block of limit switch AH-KS-5037A.



As the lever arm is moved the Cam (2) starts to rotate, this causes the cam follower to move in direction B. The Shuttle (5) is locked in place by Latches (8) which are engaged with the lower fingers (10) of the shuttle. This in turn causes the Floating Arm (6) to compress Spring (7) with resultant force in direction C. Operating Pin (11), an integral part of Cam Follower (1), moves downward as the cam continues to rotate, first releasing the upper Latches (8), they remain open and resting against the shuttle fingers, secondly the Operating Pin engages the lower latches. At a predetermined point the latches are forced open and disengage the shuttle fingers. At this point force C goes into action and snaps Shuttle (5) to the down position, contact transfer now takes place.

4 2124

Figure 14. Exploded view of the switching mechanism of NAMCO series EA700 switches.

The actuator shaft bushings, which appeared to be like Teflon or Bakelite, were brittle and partly chipped at the exposed end section. The unexposed section is also brittle, but its physical appearance is clean and unaffected by the accident. Their fit to their respective actuator shaft was snug and permitted no lateral play of the shaft, which made the switch actuation and reset points consistent.

A break of the contact barriers on the contact block of three limit switches was also noted, as seen in Figure 13. Judging from the way the limit switches were wired in the field, with AWG #12 conductors terminated on terminals C and D by AMP PIDG ring torque terminal lugs, it appears that the barriers were probably intentionally broken by construction electricians to provide room for the wires and lugs and allow ease of termination. The action degraded the dielectric property of the device; however, it did not cause degradation below the minimum requirement of 2200 V ac.

CONCLUSIONS AND RECOMMENDATIONS

Overall, the solenoid valve assembly and the limit switches survived the TMI-2 accident with no deleterious effect on their function. Although the devices stayed in the containment and operated for about four more years after the accident, only minimal degradation attributable to the accident was observed. Most of the defects noted developed from normal use or were created by personnel.

Despite the air leak within the solenoid valve assembly, caused by the presence of rust flakes in the valve and cracks in the valve instrument air tubing nuts, the valve operated normally at a slightly reduced response time. The acetal plastic disk holder and bottom plug of the pilot valve and the Buna-N main disks, O-rings, and gaskets considered as the weak points of the valve assembly, remained pliable and unaffected by the accident.

Examination of the solenoid valve assembly revealed no noticeable effect from the accident on any of the parts. Despite the devices exposure to an estimated dose on the order of 10^6 rads, the acetal plastic reported in NRC Bulletin 79-01A to have a maximum service limit of 400,000 rads remained in good service condition. Nevertheless, while the acetal plastic and Buna-N survived the relatively "mild" accident, they may not be able to survive a design basis accident. As indicated in the NRC bulletin, the acetal plastic and Buna-N parts must be replaced by metal and ethylene propylene or viton elastomers, respectively, if the solenoid valve is to be used for a Class 1E function inside the primary containment.

Although NAMCO model EA740-20000 switches are now LOCA-qualified, the limit switches examined are not. The nonmetallic bushings for the switch actuator shafts make them unqualified for their intended use. Current models (made after 1978) use brass bushings, thus eliminating the vulnerability presented by the nonmetallic parts. While this switch model is qualified for LOCA use, it contains a number of nonmetallic parts which are vulnerable to aging. To maintain the switch LOCA qualification, the manufacturer recommends a regular maintenance of the device which includes replacement of the nonmetallic parts.

Finally, although it is customary and even a requirement to clean piping when first installed in a nuclear plant, the presence of rust flakes in the solenoid valve suggests that the instrument air piping is not sufficiently cleaned. Although a thorough cleaning of the piping is normally performed during startup, the process does not guarantee that the piping is absolutely clean. Because a small amount of dirt could compromise the proper functioning of the device, a leak test on the solenoid valve should be performed regularly to enhance performance reliability.

APPENDIX A

U.S. NUCLEAR REGULATORY COMMISSION IE BULLETIN NO. 79-01A

UNITED STATES
NUCLEAR REGULATORY COMMISSION
OFFICE OF INSPECTION AND ENFORCEMENT
WASHINGTON, D.C. 20555

June 6, 1979

IE Bulletin No. 79-01A

SUPPLEMENT NO. 79-01A TO IE BULLETIN 79-01 - ENVIRONMENTAL QUALIFICATION OF CLASS 1E EQUIPMENT (DEFICIENCIES IN THE ENVIRONMENTAL QUALIFICATION OF ASCO SOLENOID VALVES)

Description of Circumstances:

Recently, a noncompliance report under 10 CFR Part 21 was received by the NRC from the Henry Pratt Company, manufacturer of butterfly valves which are installed in the primary containment at the Three Mile Island Unit 2 Nuclear Station. These butterfly valves are used for purge and exhaust purposes and are required to operate during accident conditions. The report discusses the use of an unqualified solenoid valve for a safety-related valve function which requires operation under accident conditions. The solenoid valve in question is Catalogue No. HT-8331A45, manufactured by the Automatic Switch Company (ASCO) of Florham Park, New Jersey. This pilot valve is used to pilot control the pneumatic valve actuators which are installed on the containment ventilation butterfly valves at this facility.

The deficiency in these solenoid valves identified in the Part 21 Report concerns the parts made of acetal plastic material. The acetal disc holder assembly and bottom plug in the pilot valve assembly are stated by ASCO to have a maximum service limit of 400,000 Rad integrated dosage and 200 degrees F temperature. According to ASCO, exposure of these acetal plastic parts to specified maximum environmental conditions may render the solenoid pilot valve inoperable which would cause the associated butterfly valve to malfunction.

Further investigation at ASCO by the NRC staff has revealed that the valve seals in most ASCO solenoid valves contain Buna "N" elastomer material, which reportedly has a maximum service limit of 7,000,000 Rad integrated dosage and 180 degrees F temperature. The investigation further revealed that ASCO has available a line of qualified solenoid operated pilot valves (ASCO Catalogue No. NP-1) which have no plastic parts, utilize ethylene propylene or viton elastomers and have a continuously energized operating life of four years, under normal ambient conditions up to 140 degrees F. According to the manufacturer, at the end of this period, the coil, manual operator (optional feature) and all resilient parts must be replaced. These preventive maintenance instructions are specified in the installation and instruction bulletins which are provided to the purchaser with each shipment of solenoid valves.

The final items of concern identified during this investigation deals with the application of Class "A", "B", or "F", solenoid coils which are exposed to an accident environment. In this regard, ASCO representatives stated that the high temperature coils identified as Class "HT" or "HB" are the only coils considered suitable for service under accident conditions; whereas, Class "A", "B", and "F" coils are not.

With respect to the corrective measures to be taken to resolve the above concerns, ASCO recommends the following:

1. The parts of the solenoid valve made of acetal plastic material should be replaced with similar parts made of metal which can be provided by ASCO.

2. The valve seals and gaskets which are made of Buna "N" material should be replaced with either ethylene propylene or viton elastomers, considered by ASCO as suitable for the service intended.

3. Review and determine that the coils of the solenoid valves installed inside containment are Class "HT" or "HB" as required for high temperature environmental conditions.

4. Review and determine that the solenoid enclosures installed inside containment have at least a NEMA 4 enclosure rating.

5. Establish a preventive maintenance program to assure replacement of those valve parts identified above in the time period recommended in the appropriate ASCO valve bulletin.

6. ASCO also stated that all unqualified solenoid valves inside containment be retrofitted to qualified ASCO No. NP-1 valves in lieu of the above.

7. Questions from licensees to ASCO concerning corrective measures should reference both catalogue and serial numbers of each valve in question. These numbers are stamped on the metal nameplate on each solenoid valve.

Action to be Taken by Licensees of all Power Reactor Facilities (except those 11 SEP Plants listed on Enclosure 3) with an Operating License:

1. Determine whether or not ASCO solenoid valves are used or planned for use in safety-related systems at your facility(ies).

2. If such valves are used or planned for use, identify the safety system involved and determine that: (a) valves which could be subjected to a LOCA environment are qualified to that environment. Specifically that no parts made of acetal plastic or Buna "N" materials or Class "A", "B", or "F" solenoid coils are used in such valves; (b) a preventive maintenance program is being conducted such that the solenoid coil, the manual operator (if applicable), and the resilient parts of the valve are being replaced in accordance with the time period established by the manufacturer and documented as the qualified life of the assembled component.

3. All holders of operating licenses of power reactor facilities are obligated to meet the review and reporting requirements established in previously issued IE Bulletin 79-01, regarding environmental qualification of electrical equipment installed in their plants.

No additional written response to this Supplement IE Bulletin is required other than those responses described above. NRC inspectors will continue to monitor the licensees' progress in completing the requested action described above. If additional information is required, contact the Director of the appropriate NRC Regional Office.

Approved by GAO, B180225 (R0072); clearance expires 7/31/80. Approval was given under a blanket clearance specifically for identified generic problems.

APPENDIX B

TEST RESULTS OF AH-EP-5039 AND AH-EP-[illegible]7

APPENDIX B

TEST RESULTS OF AH-EP-5039 AND AH-EP-5037

			Control Unit	AH-EP-5039	AH-EP-5037
DC resistance (ohms)		Cold	58.24 @ 80°F	57.1 @ 78°F	58.6 @ 84°F
		Hot	71.14 @ 132°F	66.0 @ 104°F	68.8 @ 110°F
Inductance (air core) (mH)	Series	100 Hz	423	440	433
		1 kHz	244	272	263
	Parallel	100 Hz	487	490	480
		1 kHz	335	356	349
Equivalent series resistance (ohms)	Series	100 Hz	188	173	173
		1 kHz	1000	1096	1038
	Parallel	100 Hz	1620	1825	1800
		1 kHz	3900	4200	4200
Coil current @ 102 V ac (mA)		Cold	167.5 @ 77°F	167.6 @ 73°F	168.2 @ 73°F
		Hot	165.6 @ 119°F	164.5 @ 101°F	163.5 @ 114°F
Hold current @ 120 V ac (mA)		Cold	228.0 @ 78°F	230.3 @ 74°F	228 @ 75°F
		Hot	224.5 @ 130°F	225.0 @ 101°F	223 @ 114°F
In-rush current @ 120 V ac (mA)			617.0 @ 79°F	641 @ 80°F	636 @ 83°F
Coil impedance (air core) @ 60 Hz (ohms)		Cold	252 @ 80°F	243.2 @ 75°F	240.4 @ 75°F
		Hot	262.5 @ 130°F	250.0 @ 102°F	249.2 @ 114°F
Sol. power input impedance @ 120 V ac (plunger in) (ohms)		Cold	522 @ 81°F	524 @ 75°F	529.1 @ 76°F
		Hot	534.6 @ 130°F	533.3 @ 102°F	538.6 @ 114°F
Sol. P.F. (plunger in)		Cold	0.404 @ 81°F	0.411 @ 75°F	0.405 @ 76°F
		Hot	0.406 @ 130°F	0.400 @ 102°F	0.407 @ 114°F
Sol. power (W) (plunger in)		Cold	11.19 @ 81°F	11.4 @ 75°F	11.03 @ 76°F
		Hot	10.93 @ 130°F	10.81 @ 102°F	10.89 @ 114°F

		Control Unit		AH-EP-5039		AH-EP-5037	
Sol. VA (plunger in)	Hot	27.72	@ 81°F	27.72	@ 75°F	27.27	@ 76°F
	Cold	26.94	@ 130°F	27.00	@ 102°F	26.78	@ 114°F
Pull-in voltage	Cold	80.45	@ 78°F	82.15	@ 77°F	81.2	@ 77°F
	Hot	79.16	@ 140°F	77.25	@ 102°F	83.3	@ 114°F
Dropout voltage	Cold	55.98	@ 78°F	51.86	@ 77°F	52.7	@ 77°F
	Hot	52.50	@ 140°F	51.76	@ 102°F	53.7	@ 114°F
Response time (ms)	Pull-in	72.35		82.43			
	Dropout	131.68		142.2			
Internal leakage	D-E			0		0	
	E			0		Greater than 2 scfh	